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Title: Charged Particle Transport in FLAG

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Charged Particle Transport in FLAG

Edward Norris

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Outline

- Motivation
- Charged particle transport theory
- Implementation
- Usage
- Test Problems
- Future work

Motivation

Motivation

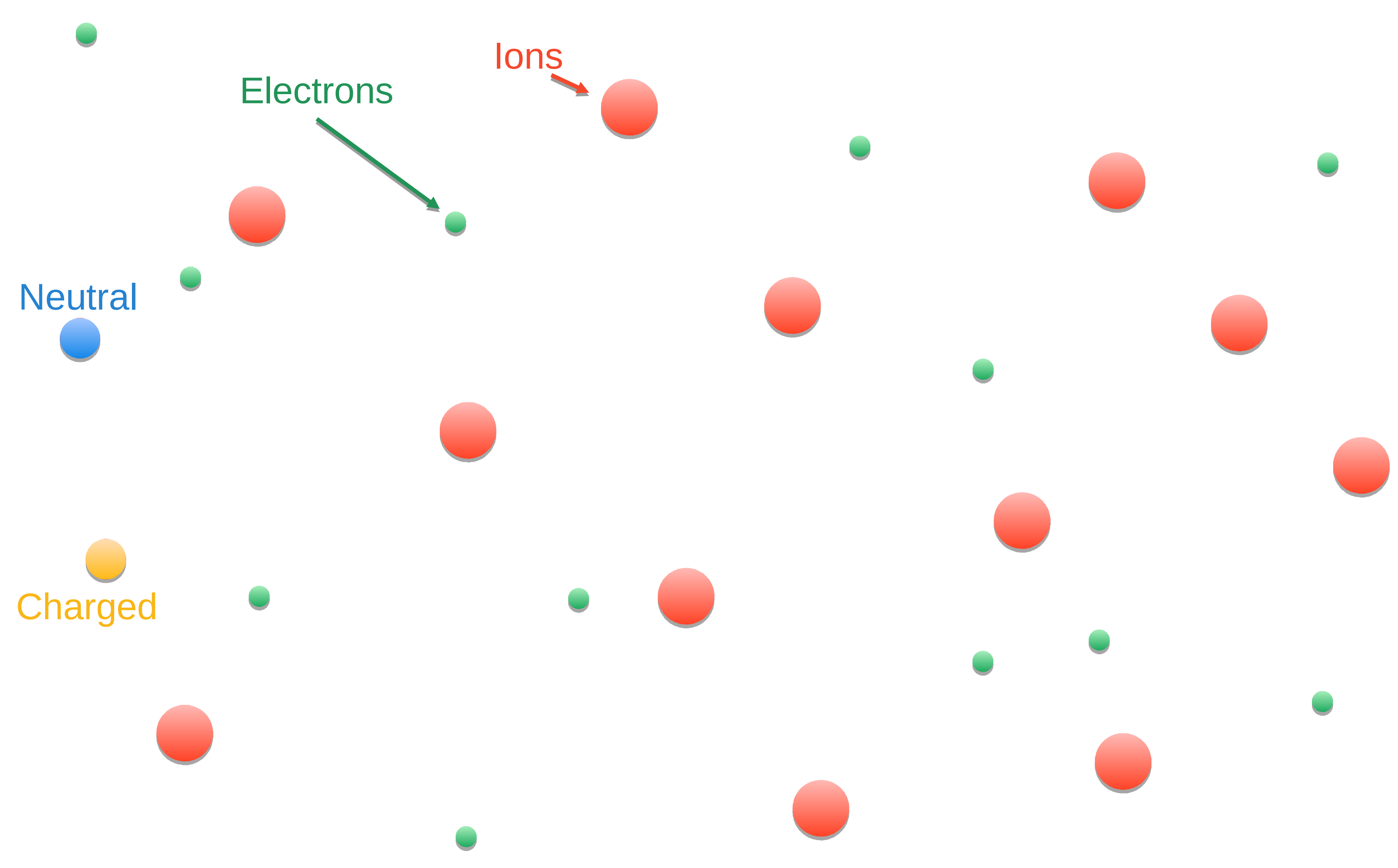
- Currently, all energy deposition is local
  - All energetic particles born in a zone deposit 100% of their energy in that zone
- Charged particles deposit energy over 10s to 100s of microns.
- As advanced hardware and ICF capsule design drives zone sizes below this threshold, local deposition is no longer a good approximation.
- Motivates implementation of a Monte Carlo charged particle transport package

Charged Particle Transport Theory

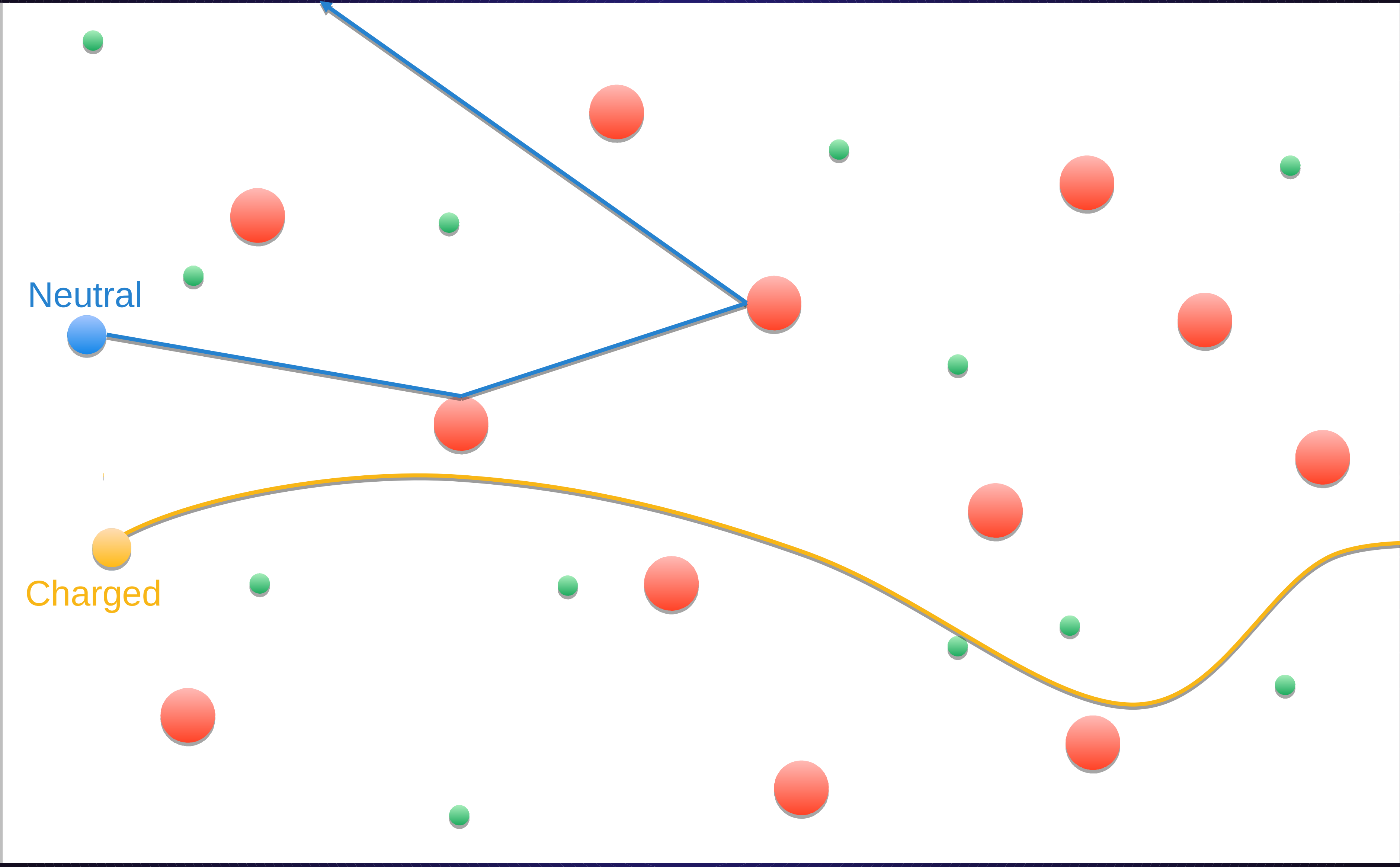
Theory

- All equations implemented must use SI units!

Theory

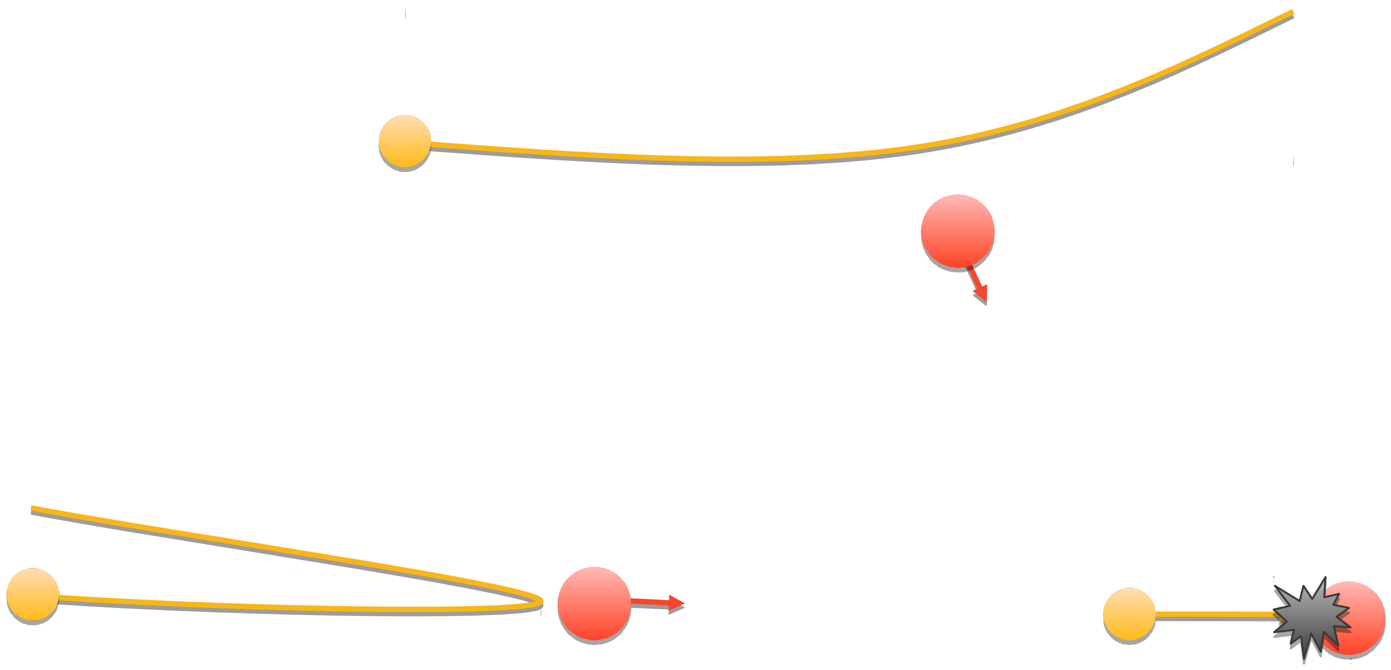


Theory



Theory

- As particles move around, they undergo two types of interactions:
  - Small angle scatter
  - Catastrophic interactions



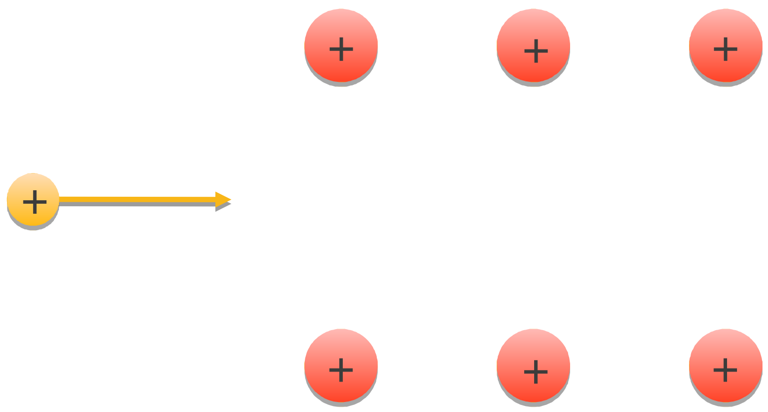
Theory

- Small angle scatter is dominated by Coulombic interactions
  - Each small path length can be treated as a line
  - Advance the particle, compute the energy loss, repeat
  - Assume that on average, scatters cancel out and the particle travels in a straight line
- Catastrophic interactions result in the particle being killed off
  - Local energy deposition wherever the particle is
  - **Not modeled yet**

- Currently, particles travel in a straight line and deposit energy as they trave.

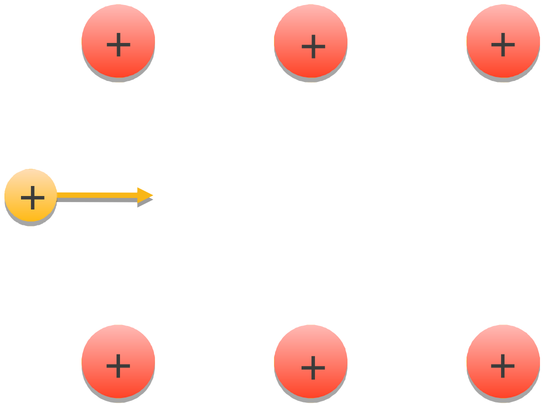
Theory

- Consider a charged particle flying through a “tunnel” of ions



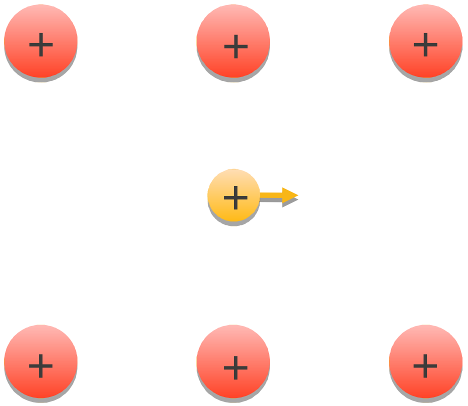
Theory

- The particle slows as it is repelled



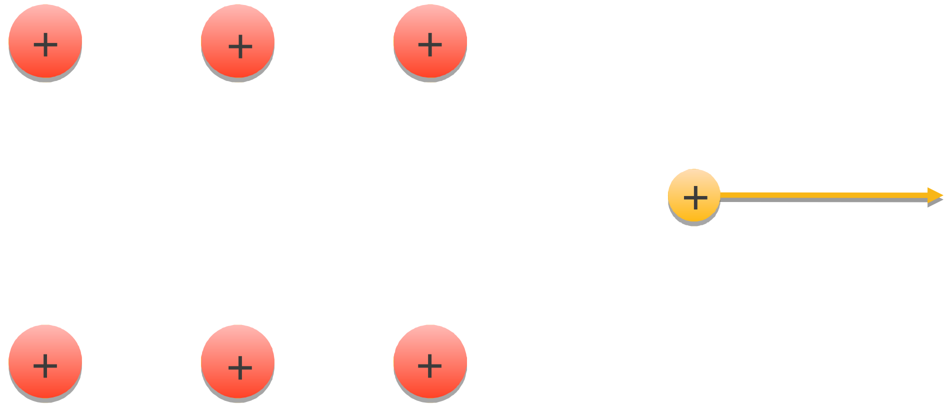
Theory

- Halfway, there is no net force on the particle



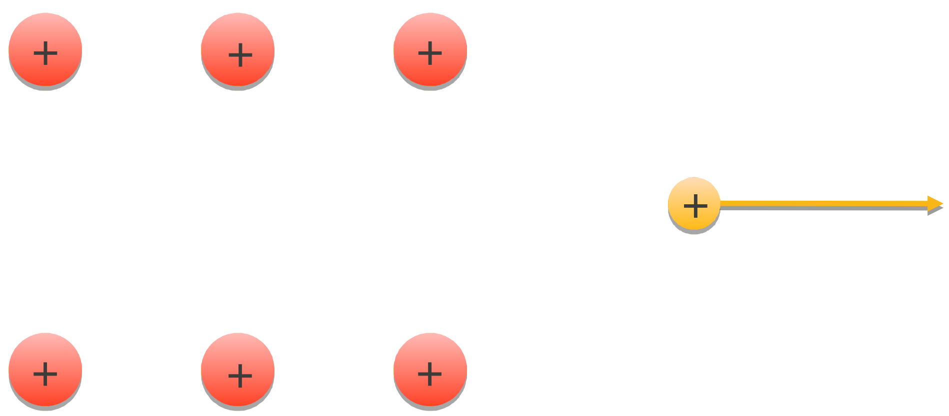
Theory

- On the way out, the particle is repelled and accelerates. It gains the same amount of energy it lost going in.



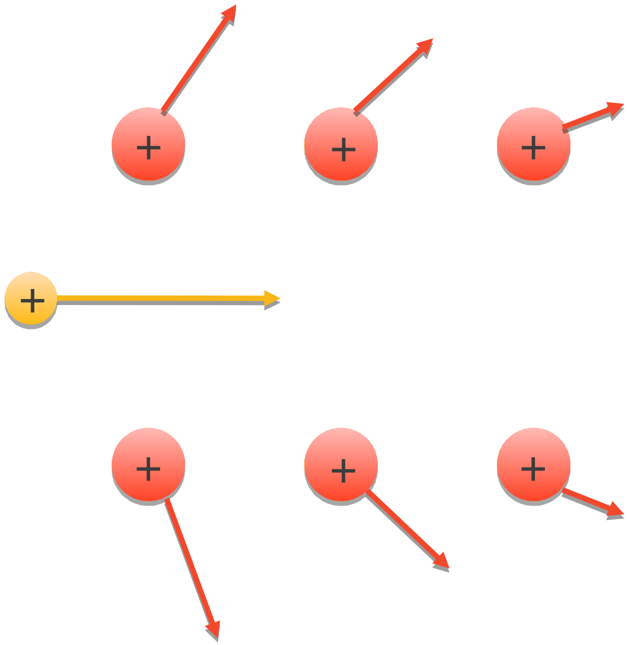
Theory

- How can charged particle interactions result in an energy transfer?



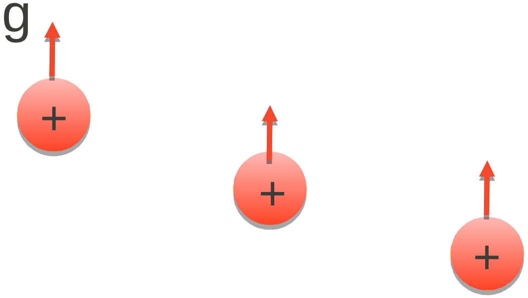
Theory

- As the particle approaches, it accelerates the ions and they move further away



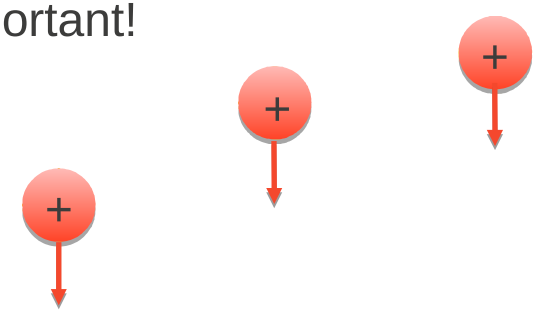
Theory

- And the particle is not accelerated while leaving as much as it was decelerated entering

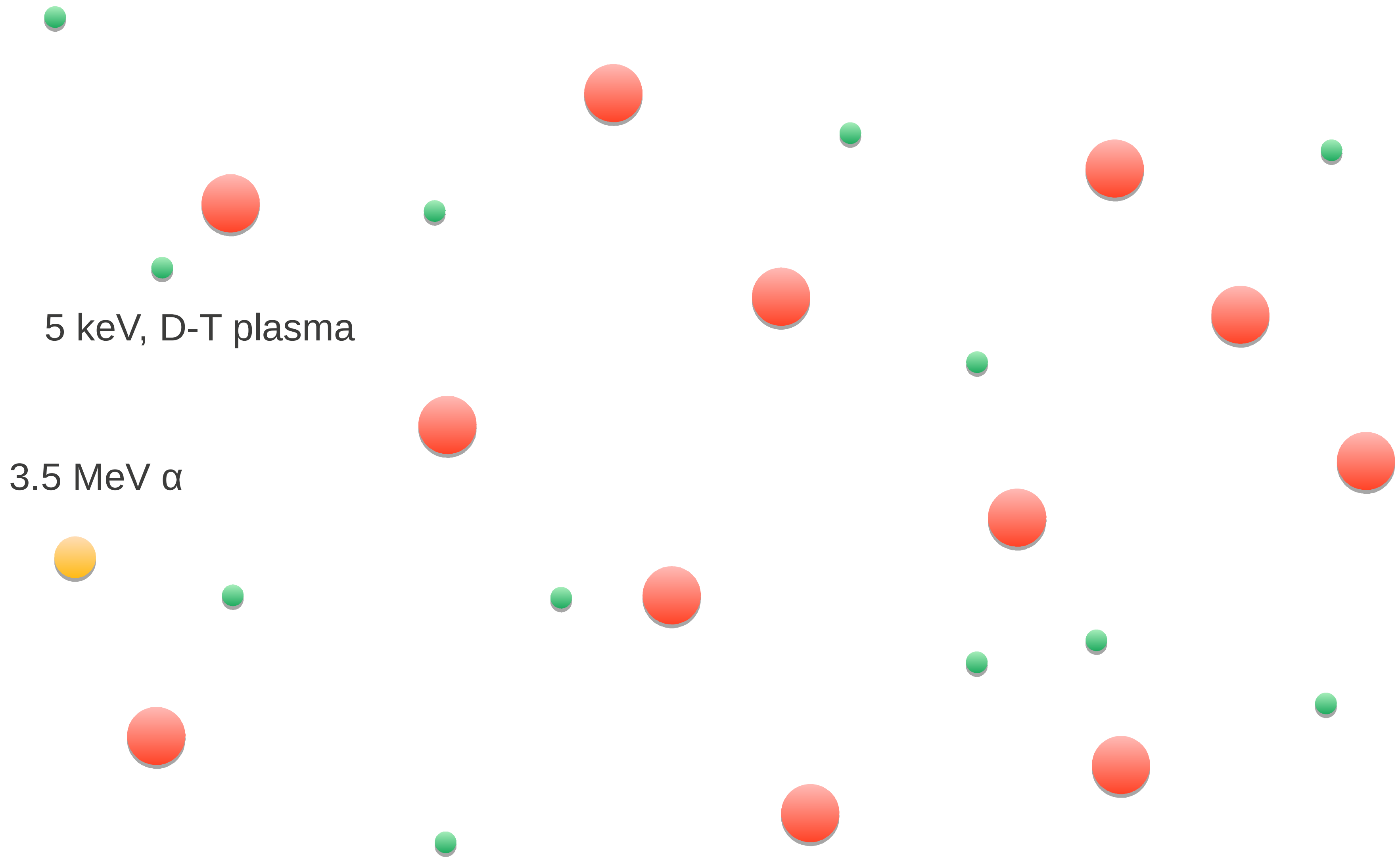


The energy imparted to the ions is equal to the loss in energy of the charged particle due to the displacement of the ions

Timescale is very important!

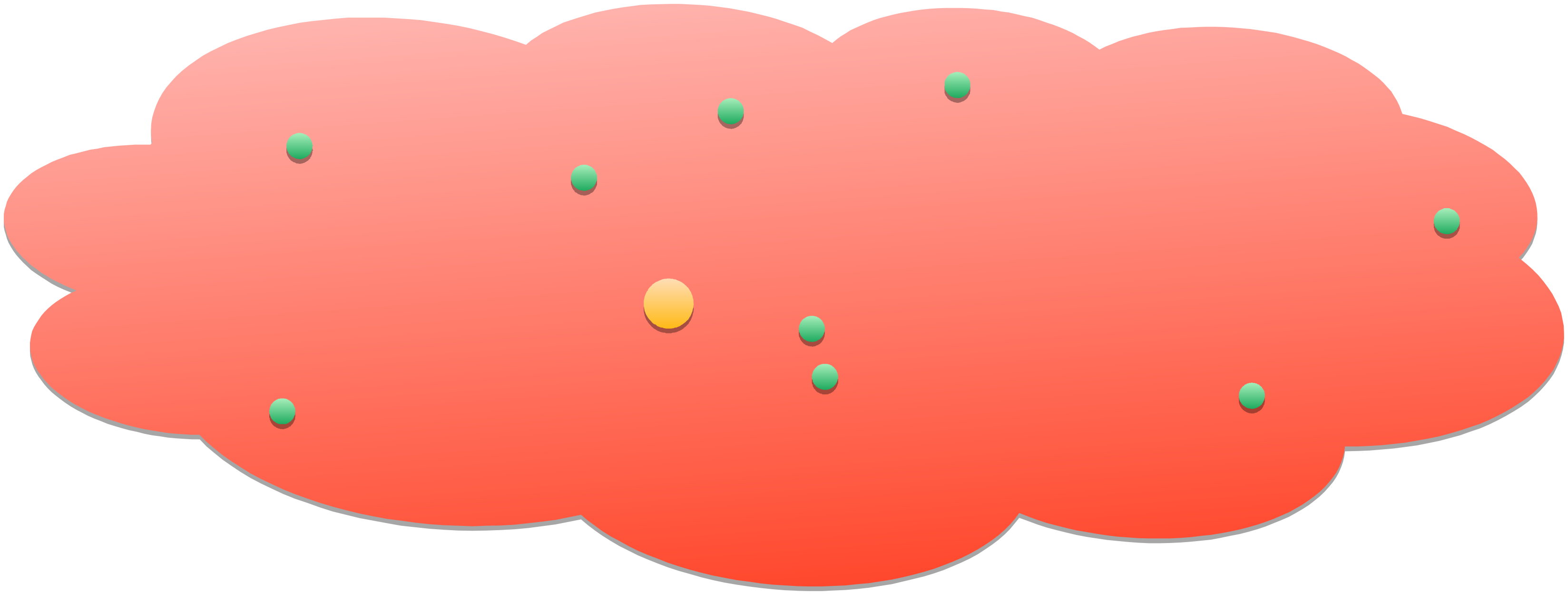


Theory



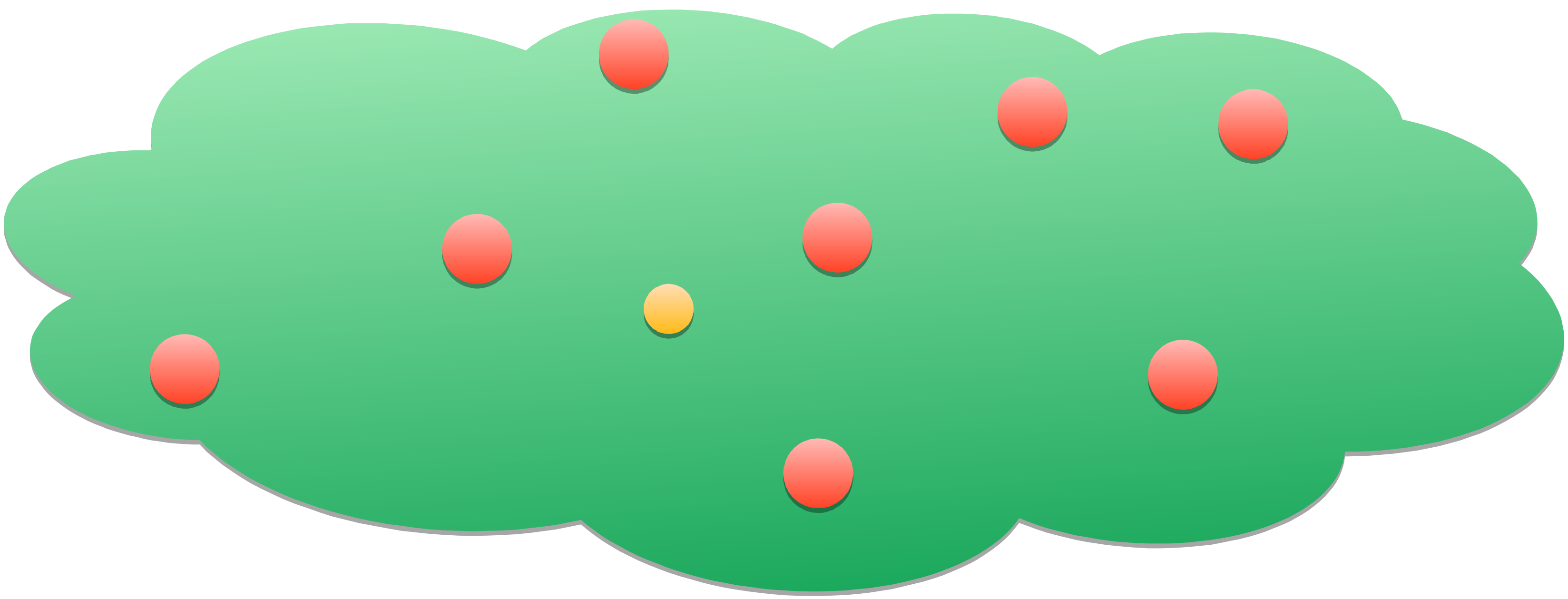
Theory

- DT Ions (m = ~2.5 amu, E = 5 keV)
  - Speed: 62.1 cm/μs
- DT Electrons (m = 0.00055 amu, E = 5 keV)
  - Speed: 4190 cm/μs
- Charged Particle (m = 4.0 amu, E = 3.5 MeV)
  - Speed: 1300 cm/μs



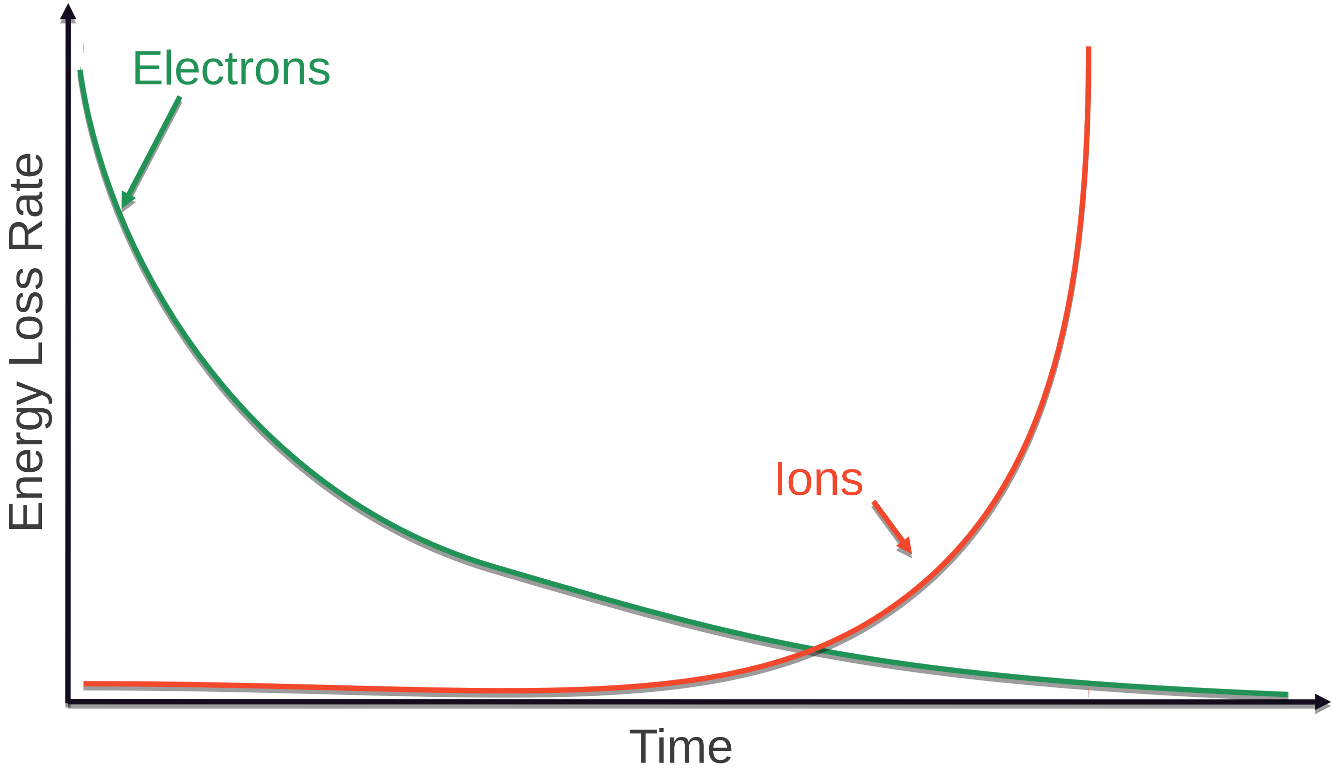
Theory

- As the charged particle interacts with electrons, it loses energy
- Eventually, the particle is going at approximately the same speed as the ions and much slower than the electrons



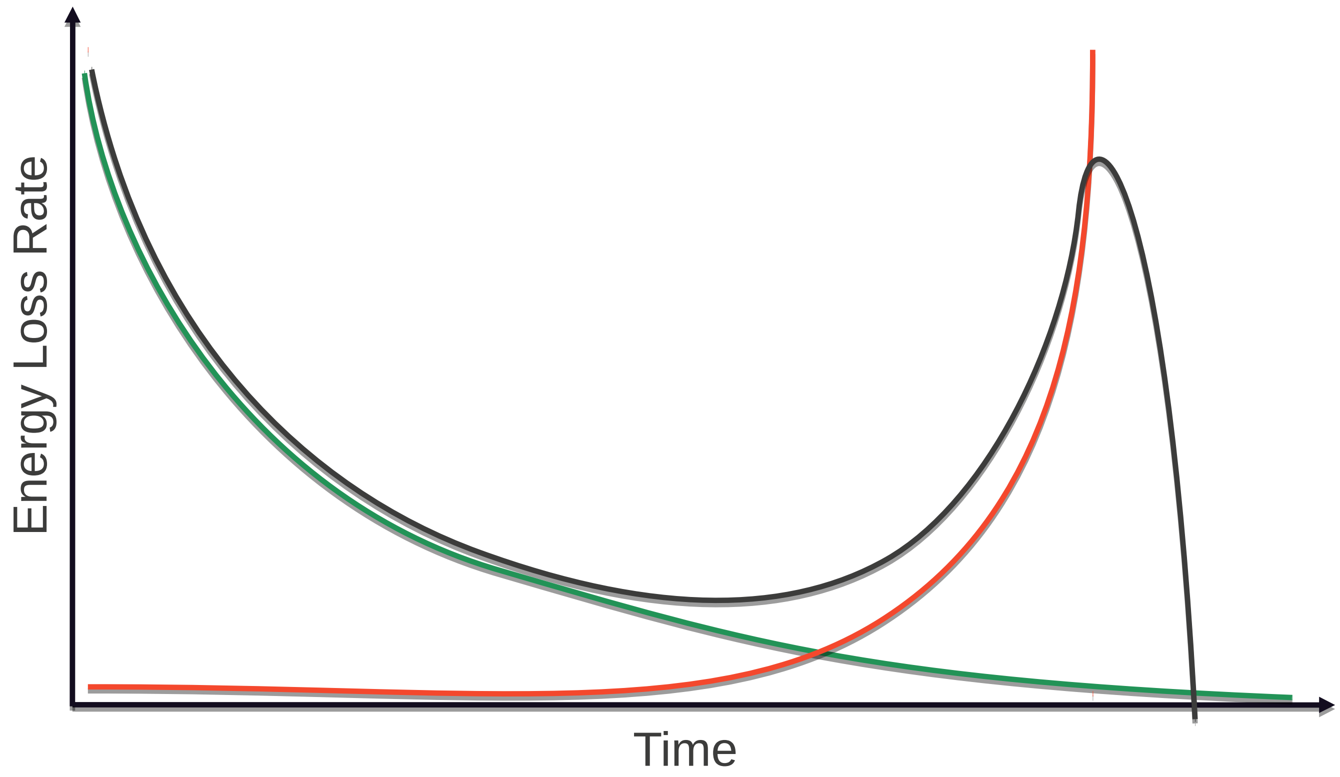
Theory

- Dominant interaction changes over time



Theory

- At some point, the particles drop to the same temperature as the background plasma and stop losing energy altogether



Theory

- Four models

  Void

  Simple

  Analytic

  dE/dx Data

No physics – particles travel in straight line and do not slow down

Based on electrons only. Has an ion correction that can be turned on

Theory

- Four models

  Void

  Simple

  Analytic

  dE/dx Data

Based on Plasma Formulary equations

Multiple datatable correlations available

Implementation

Implementation

```
DoFlagDriver(kdd)
  …
  call MixDriver(mesh)
  call SBroad('PrePhysCycle', mesh, dtg)
  call SBroad('ChargedPtclPhys', mesh, dtg)
  ncount = 0
  call SBroad('CalcEIRSrc', mesh, ncount)
  if(ncount.gt.0)then
  …
```

```
ChargedPtclPhys(this, dtg)
  call SBroad('SpawnCharged', this, dtg)
  call SBroad('MoveCharged', this, dtg)
```

```
ChargedPtclSource(this, dtg)
  call SBroad('ChargedPtclSrcRealRate', …)
  call SBroad('ChargedPtclSrcMcRate', …)
  …
  call List_increment(…)
  call ChargedPtclSourceCreate(…)
```

```
ChargedPtclTransport(this, dtg)
  cpt_timestep = …
  substeps = …

  do j = 1, substeps
    call SBroad('ChargedPtclTransportStep', …)
  enddo

  call ChargedPtclTransportStats(...)
  call ChargedPtclEnergyDep(…)
```

Usage

Usage

mk /global/mesh/particle/charged_ptcls
mk +source/position/…
mk +source/direction/…
mk +source/energy/…
mk +source/zaid/…
mk +source/charge/…
mk +source/mass/…
mk +source/real_rate
mk +source/mc_rate
mk +transport/…

```
charged_ptcls
  source
    position
    direction
    energy
    zaid
    charge
    mass
    real_rate
    mc_rate
  transport
```

Test Problems

Test Problems

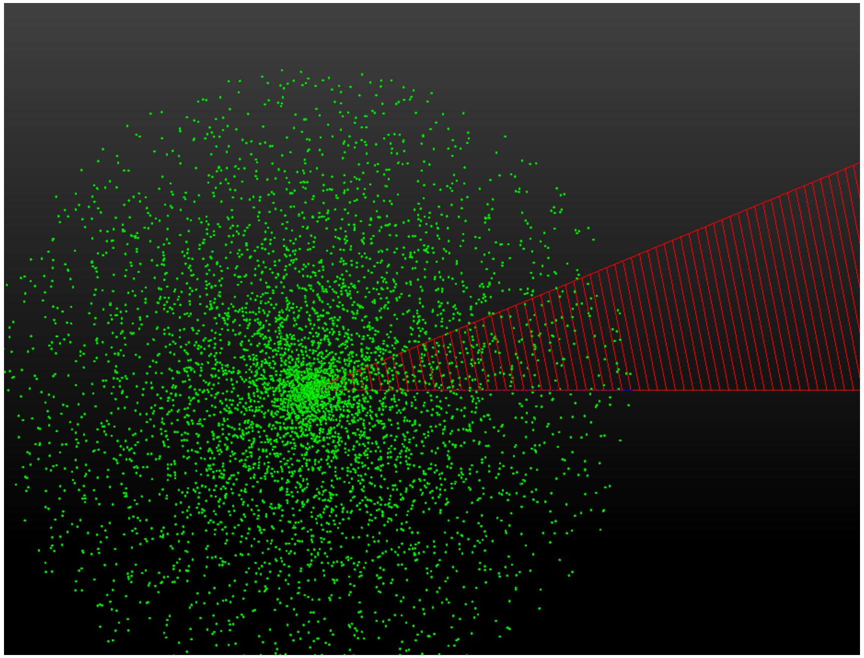
Problem #1

1D Spherical

Isotropic point source

Exercises particle tracking

No physics



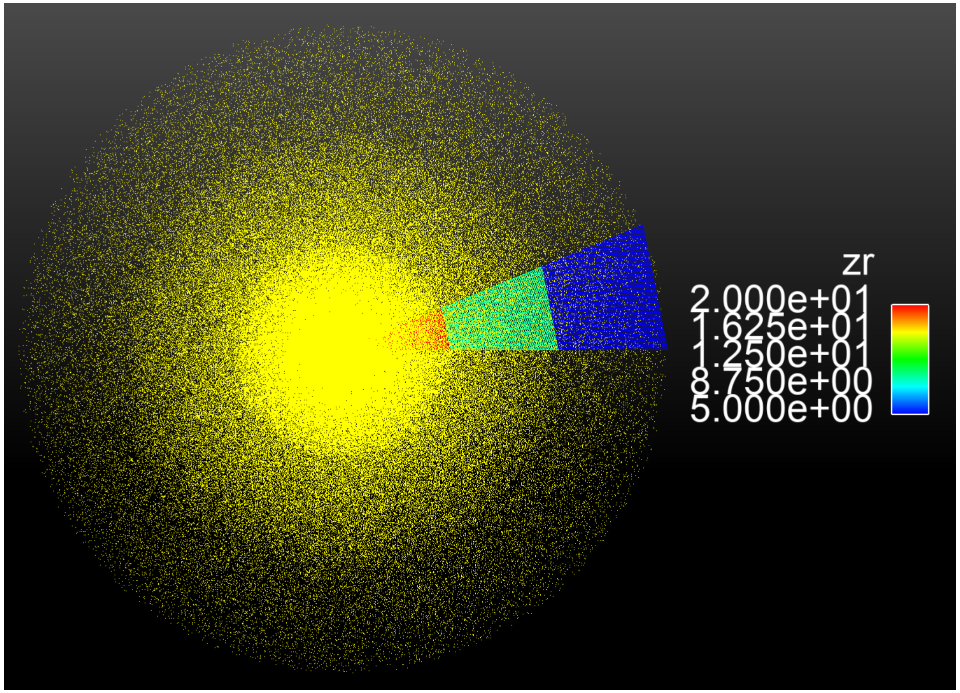
Test Problems

Problem #2

1D Spherical

Zonal source (weighted by zone density)

Simple transport



Test Problems

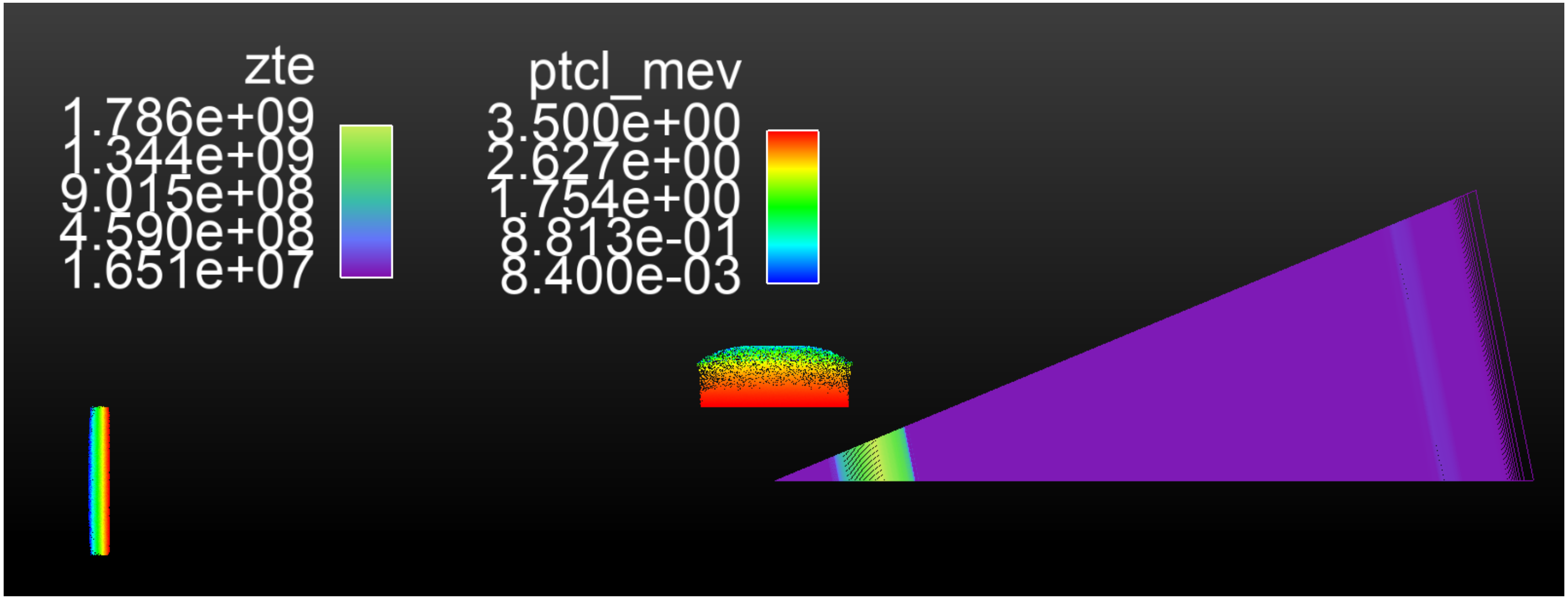
Problem #3

1D Spherical

Two mono-directional disk sources (1 particle node)

Energy coupling to matter

Exercises ALE+Hydro

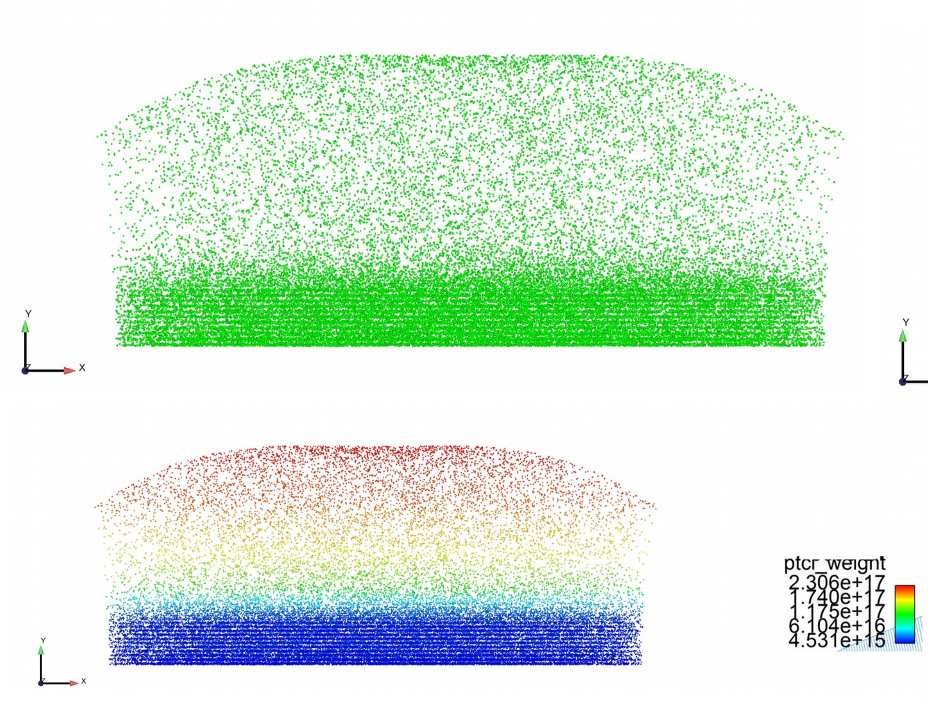


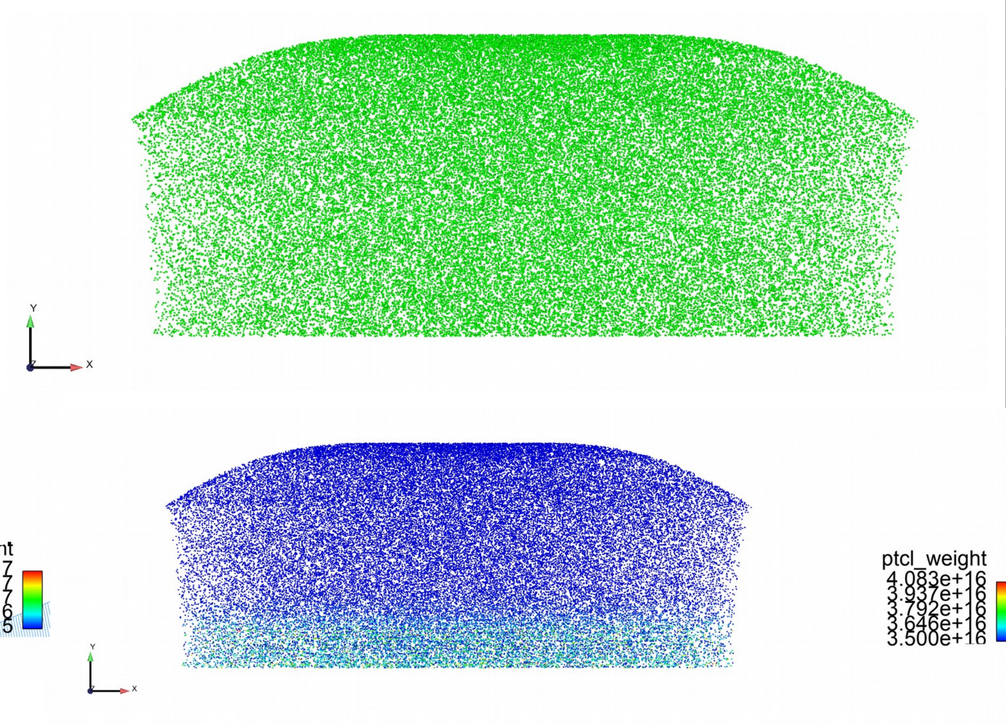
Test Problems

Problem #3

50 Particles Per Cycle

5 < Particles Per Cycle < 500
Weight preference = 3.5E16





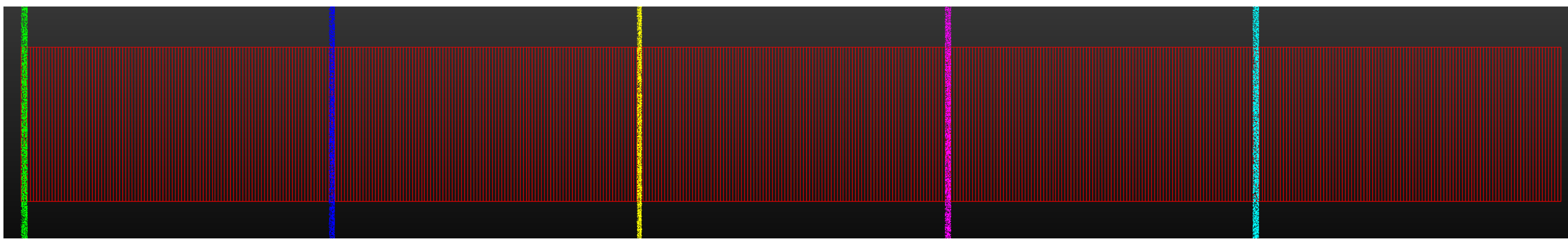
Test Problems

Problem #4

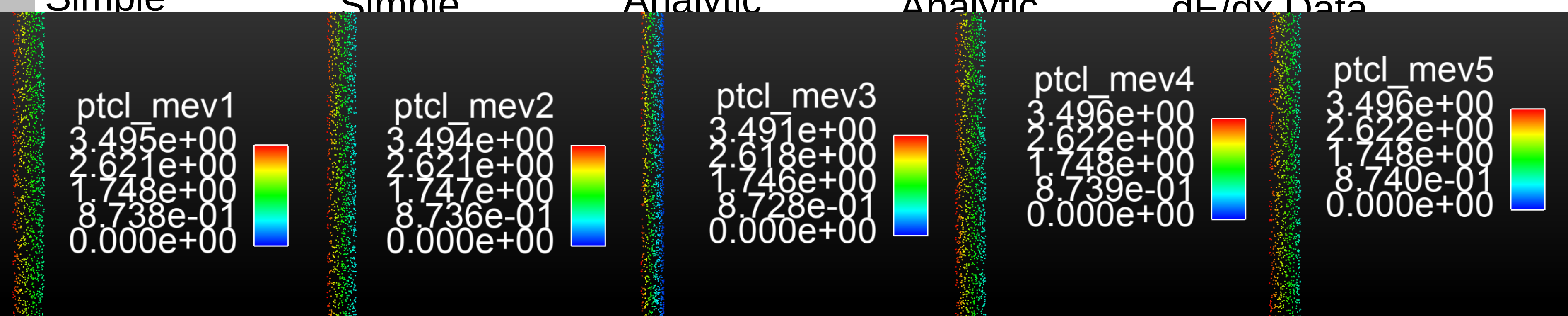
1D Cartesian

Five mono-directional disk sources (5 particle nodes)

Apple-to-apple comparison of transport methods



Simple Simple Analytic Analytic dE/dx Data



Test Problems

Problem #4

1D Cartesian

Five mono-directional disk sources (5 particle nodes)

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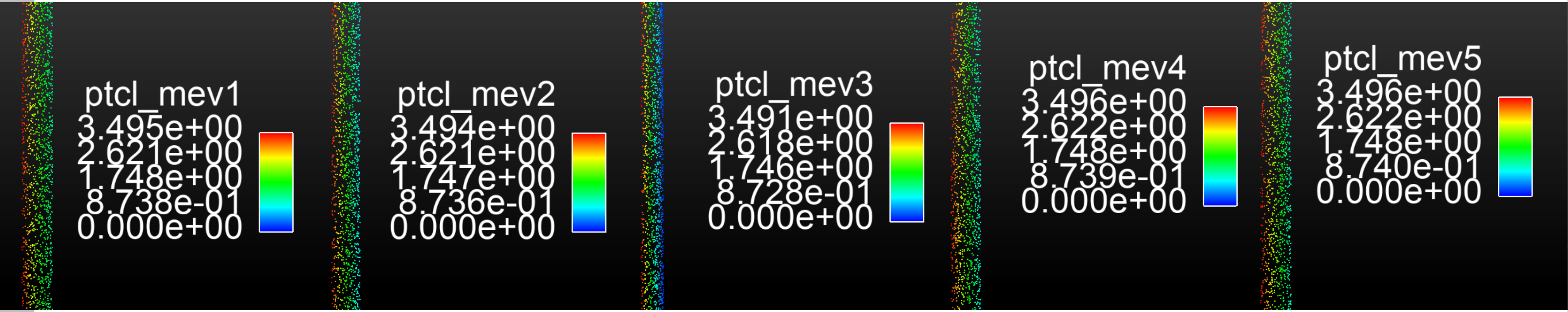


Simple

Simple + Ion Correction

Analytic Approx. dv/dt

Analytic Exact dE/dt

dE/dx Data

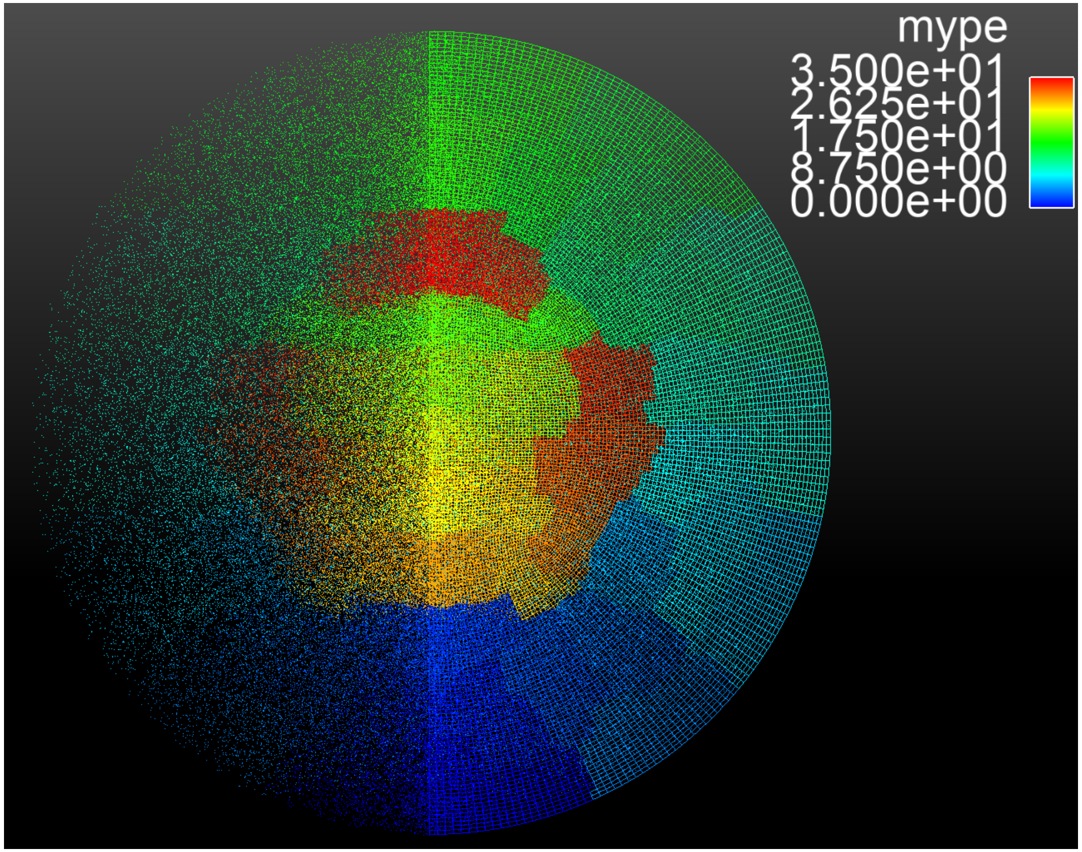
Test Problems

Problem #5

2D Cylindrical

Zonal distribution in DT

36 cores on 1 node



Future Work

Future Work

- More 2D tests
- 3D tests
- Quantitative comparison between transport methods